TELEMETERING OF ACCELERATIONS ON FREE-FLIGHT

MODELS IN HYPERSONIC TUNNELS

by

D. R. Harrison, W. K. Lockman, and G. W. Coon

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

Presented at Twenty-Third Semiannual Meeting
of the Supersonic Tunnel Association

Long Island, New York
May 3-4, 1965

(FOR USE OF STA MEMBERS ONLY - NOT TO BE REFERENCED)

INTRODUCTION

Recent telemetry developments at Ames Research Center have been concerned with applying telemetry to free-flying models in hypersonic tunnels. A previous report has described miniature units for telemetering pressure or heat-transfer data (see ref. 1). The purpose of this paper is to report further developments at Ames for telemetering accelerations due to drag and pitching motion.

The telemetry system is described with particular emphasis on the design of the accelerometer. The results of preliminary tests to measure drag and pitching motions of cones in free flight are presented and examined to assess the usefulness of the technique.

NOTATION

a	acceleration
C	capacitance
C_D	aerodynamic drag coefficient
C_{m_α}	rate of change of aerodynamic pitching-moment coefficient with angle of attack
D	aerodynamic drag force
f	frequency
g	acceleration due to gravity
h_t	total enthalpy
M_∞	free-stream Mach number
p_{t_1}	tunnel reservoir pressure
q_∞	free-stream dynamic pressure
S_b	cone base area
W	model weight
Δ	incremental change
θ	pitch angle

TELEMETRY SYSTEM

The basic system used frequency modulation (FM) with the carrier frequency set at 115 Mc. This frequency is chosen to avoid broadcast interference. The telemetry receiver has a tuning range of 105 to 140 Mc and a linear response (to 1 percent) for a

[redacted]

frequency deviation to ±0.5 Mc. The modulation of the carrier frequency is produced by acceleration acting upon a capacitive accelerometer located in the tuned circuit of the carrier oscillator. The incremental change in the accelerometer capacitance is designed to provide a frequency deviation within ±0.5 Mc for the maximum acceleration expected. The resulting linearity of the system, including the accelerometer, was estimated to be within 3 percent. A description of the telemetry circuit and the accelerometer follow with emphasis given to the design, construction, and calibration of the accelerometer.

Telemetry Circuit

Both drag and pitching telemetry use the circuit shown in figure 1, with the pitching telemeter modified to account for the additional capacitance of a second accelerometer connected in parallel. The circuit consists of a simple transistorized Colpitts oscillator. The temperature compensation provided by the thermistor results in a frequency stability of about 10 kc per degree centigrade. This stability can be substantially improved when it is convenient to make the cell capacitance large compared to the collector-to-base capacitance of the transistor. Power for better than 20 hours of service is supplied by two, 1.3-V mercury cells. The inductance of the tuned circuit provides an adequate antenna for coupling power to the single-loop receiver antenna mounted on the tunnel window.

Accelerometer

The capacitive accelerometer, illustrated in figure 2, is similar to the capacitive pressure cells previously used with the telemetry system (ref. 1). The accelerometer is comprised of two parts, a base and a metal cap. The base is machined from a commercially available electrical feed-through of high vacuum quality. The diaphragm is made an integral part of the base by spot-welding it onto the cylindrical rim of the base. To complete the assembly, the metal cap is soldered on the base so that atmospheric pressure is hermetically sealed inside the accelerometer. Small holes near the rim of the diaphragm assure equal pressure on each side of the diaphragm.

The physical parameters of mass, spring constant, and damping characteristics are provided in a minimum of space. The seismic mass consists of two thin, high-density disks welded to the center of the stretched circular diaphragm. The diaphragm provides the spring restoring force. The damping is produced by the air set in motion by the mass-diaphragm displacements. The motion of the mass, in response to accelerations of the case, is measured as a small change of capacitance between the mass-diaphragm assembly and the fixed electrode composed of the central rod and the platinized area on the glass.

The initial accelerometer capacitance of approximately 6 pF was obtained by choosing appropriate electrode spacing and diameter. The incremental capacitance change, ΔC, of 0.10 pF, required for the specified telemetry frequency deviation, was achieved for any particular acceleration range by selecting in proper proportion the values of mass, diaphragm stiffness, and electrode spacing. The frequency response of the transducers used was flat within 1 percent from 0 to 300 cps. The damping of the diaphragm, which modifies the frequency response, was made independent of external pressure by the hermetic sealing of the accelerometer. The measured hysteresis was in the order of 0.1 percent of full scale. Temperature effects have been minimized by careful selection of cell materials and geometry. The sensitivity change with temperature is less than 0.04 percent per degree centigrade. In view of the foregoing, the accelerometers were believed to be adequate for the tunnel free-flight tests.

Dynamic calibrations were made by using a linear shaker calibrator manufactured by Unholtz-Dickie Corp. As a result of the frequency response including 0 cps, a static 2g check of the system could be conveniently obtained at any time by simply inverting the accelerometer. The use of the linear acceleration calibrator in making angular acceleration calibrations is described in the section entitled, "Pitching Motion."

TEST RESULTS

To demonstrate the usefulness of this accelerometer-telemetry technique, drag data and pitching motion data were determined for cone models in free flight.

Drag

Initial tests in the Ames 1-Foot Shock Tunnel provided telemetered drag data for a 3.7-inch long, 15° half-angle cone model. The model was suspended, at zero angle of attack, in the tunnel test section by fine nylon threads which are consumed at the start of the high temperature flow, thereby releasing the model into a free-flight motion.

Typical results are presented in figure 3 for this cone model in air at a free-stream Mach number of 14. The oscillograph traces of the telemetered drag acceleration and tunnel reservoir pressure (driving pressure) are given in figure 3. A qualitative comparison of these two traces indicates that the accelerometer responded directly to the driving pressure of the tunnel and, hence, to the model drag.

The drag acceleration data of figure 3 were reduced to the following dimensionless form by using measured values of the driving pressure:

$$\frac{D}{p_{t_1} S_b} \equiv \frac{C_D q_\infty}{p_{t_1}}$$

where

$$D = W \frac{a}{g}$$

After the initial starting transients for the tunnel, these normalized drag results (see fig. 4) are essentially constant, as expected. A nominal value of q_∞ / p_{t_1} (2.88×10^{-4}) for the shock tunnel was used to determine the cone drag coefficient, C_D, ($\doteq 0.20$) shown in figure 4. (This somewhat high value for the cone C_D agrees within 10 percent of unpublished data obtained at Ames by other techniques and may be explained, in part, by the hypersonic viscous drag effects discussed in ref. 2.)

The accuracy of the present measurement was affected primarily by an uncertainty in the tunnel dynamic pressure. However, the accelerometer-telemeter system is believed to be in error by less than 5 percent when measuring model drag. It is believed that with foreseeable improvements in calibrating and recording techniques this error can be reduced to less than 1 percent.

Pitching Motion

For the case of pitching motion, the model used was a 5-inch long, 10° half-angle cone with two accelerometers located as shown in figure 5. The two capacitive accelerometers of the telemeter were of matched sensitivity and connected in parallel within the circuit. The accelerometers were mounted on the model axis with their orientation reversed to detect angular acceleration. The parallel connection of the matched accelerometers and their reversed orientation canceled any capacitance changes due to linear accelerations common to both. Therefore, the telemeter output provides a measurement of angular acceleration only. The two accelerometers were spaced 2 inches apart to achieve the desired sensitivity. The model was carefully balanced to prevent any rolling motion during free flight.

As previously stated, the angular acceleration calibration was performed on a linear shaker. The model was mounted on the shaker with the two linear accelerometers, electrically connected in parallel, facing in the same direction, and with their diaphragms normal to the applied acceleration. With this accelerometer arrangement, the capacitance changes produced by linear accelerations add and are the same as those produced by accelerometers facing in opposite directions and mounted in a model undergoing angular acceleration.

The pitching-motion tests were made in the Ames 20-Inch Helium Tunnel at a free-stream Mach number of 15 and a free-stream dynamic pressure of 4.1 psi. The free-flight motion of the model was achieved with a pneumatic launching device placed in the tunnel downstream of the test section. The launcher used at Ames (see ref. 1) is similar to that developed by Dayman (ref. 3). A small wedge attached to a streamlined strut was positioned in the tunnel upstream of the launcher and just above the flight path. As the model traveled upstream, it passed through the oblique shock wave produced by the wedge. The resulting pressure differential across the two sides of the model deflected the model, producing a pitching motion. High-speed motion pictures were taken during the test to provide a correlation between the model position and telemetered acceleration data. Simultaneous reference timing marks on both the film and the oscillograph provided synchronization of the two results.

By integration of the telemetered angular acceleration data, a continuous time history of the angular velocity and the angular position of the model can be determined. In the present case it was convenient to evaluate the constants of integration by using the pitch angle and angular velocity at maximum amplitude (where angular velocity is zero) as obtained from the film record. Figure 6 shows a comparison of the pitch angle as determined from both high-speed motion pictures and the telemetered accelerometer data. There appears to be fair agreement between the results of the two methods. The initial discrepancy may be due to detuning of the telemeter circuit by the presence of the metal shock-wave generator as the model passes by. This possible detuning effect will be checked by making the shock-wave generator entirely of nonmetallic material.

The results shown in figure 6 indicate an amplitude of about $\pm 13^{\circ}$ and a frequency of about 20 cps for the cone model. If it is assumed that the natural frequency of the oscillations is very nearly equal to the actual frequency (i.e., damping is small), then the pitching-moment derivative, C_{m_α}, for this case is approximately -0.0061 per degree. This value of C_{m_α} is within 5 percent of existing measurements for a similar 10° half-angle cone in helium and is also within 5 percent of the value determined from the film record of the present test. (These C_{m_α} results were calculated for the center of gravity located on the model axis at 50 percent of the cone length and are based on cone length and base area.) With the given model design, the oscillation frequency was too low to provide a sufficient number of cycles for an accurate determination of the damping coefficient.

CONCLUDING REMARKS

Techniques for telemetering drag or angular acceleration of free-flight models in hypersonic tunnel streams have been presented. The FM telemetry system consists of a standard telemetry receiver and a capacitive type accelerometer connected directly in the tuned circuit of the carrier oscillator. The telemeter electronic packages are small, inexpensive, and readily produced. The capacitive accelerometers have proven to be rugged, applicable to low or high g measurements, easily calibrated, and of adequate linearity and frequency response.

Some of the more obvious advantages of telemetry over the standard photographic techniques are: a continuous trace is obtained, data reduction and interpretation are greatly simplified, and in most cases the period of data acquisition is not limited to the viewing area of the tunnel windows.

The typical test result shown for cone drag is in reasonably good agreement with data obtained at Ames by other techniques. This test and the results of other tests, not reported here, have demonstrated the usefulness of the given accelerometer-telemetry technique for free-flight drag measurements. The preliminary test results for pitching were not completely adequate for the evaluation of the motion. However, they do show the potential of the technique described here. New model designs and accelerometer arrangements are currently being tested to provide more complete and accurate pitching-motion data.

REFERENCES

1. McDevitt, John B., Harrison, Dean R., and Lockman, William K.: Measurement of Pressures and Heat Transfer by FM Telemetry From Free-Flying Models in Hypersonic Tunnel Streams. Paper presented to the First International Congress on Instrumentation in Aerospace Simulation Facilities, Paris, France, Sept. 28-29, 1964.

2. Whitfield, J. D., and Griffith, B. J.: Hypersonic Viscous Drag Effects on Blunt Slender Cones. AIAA J., vol. 2, no. 10, Oct. 1964, pp. 1714-1722.

3. Dayman, Bain, Jr.: Free-Flight Hypersonic Viscous Effects on Slender Cones. AIAA Paper 64-46.

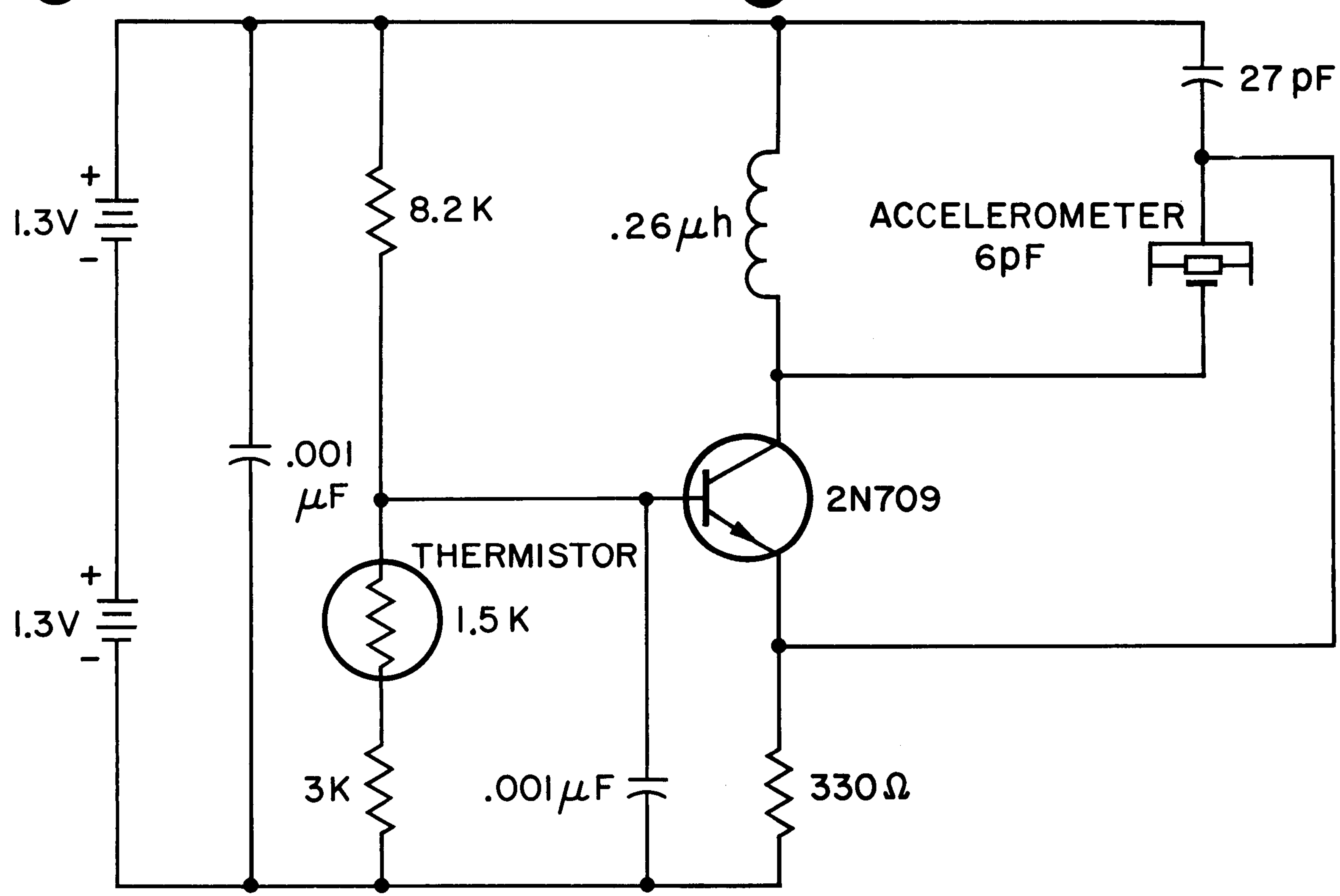

Fig. 1.- FM telemetry oscillator.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

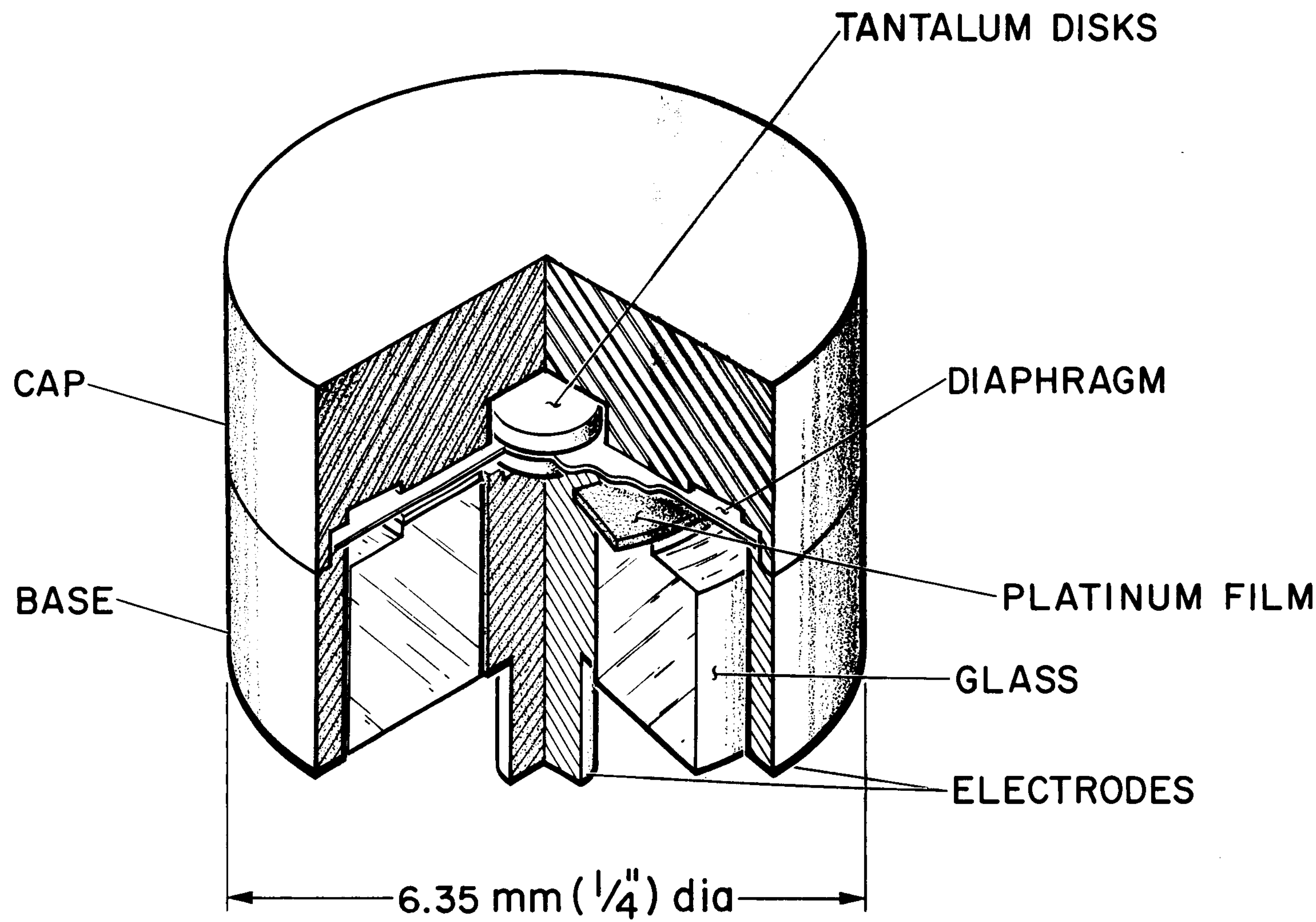

Fig. 2.- Capacitive accelerometer.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

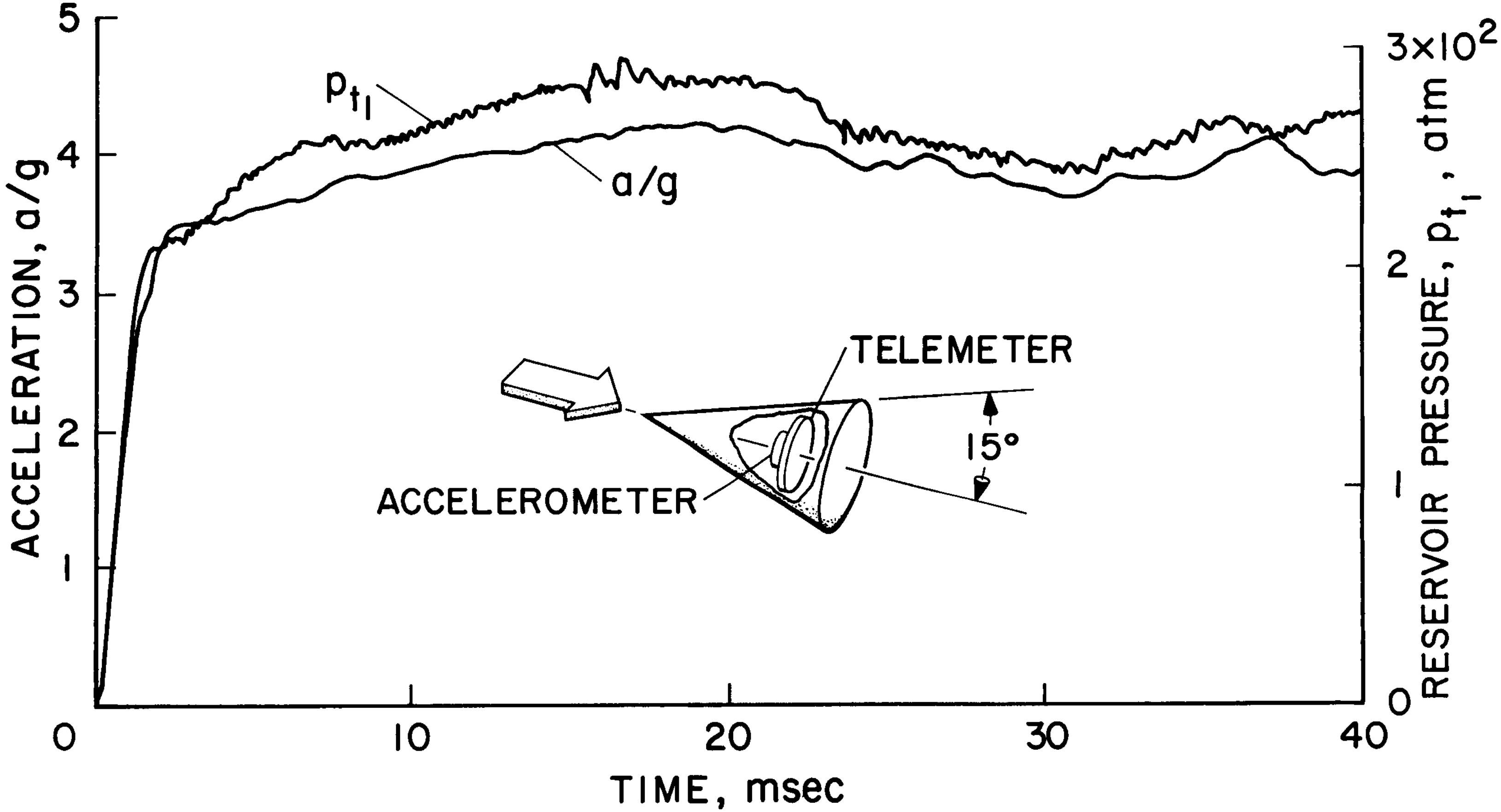

Fig. 3.- Typical oscillograph traces for drag measurement on a 15° half-angle cone in 1-foot shock tunnel ($M_\infty \approx 14$, $h_t \approx 10.7 \times 10^6$ J/kg, $q_\infty/p_{t_1} \approx 2.9 \times 10^{-4}$).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

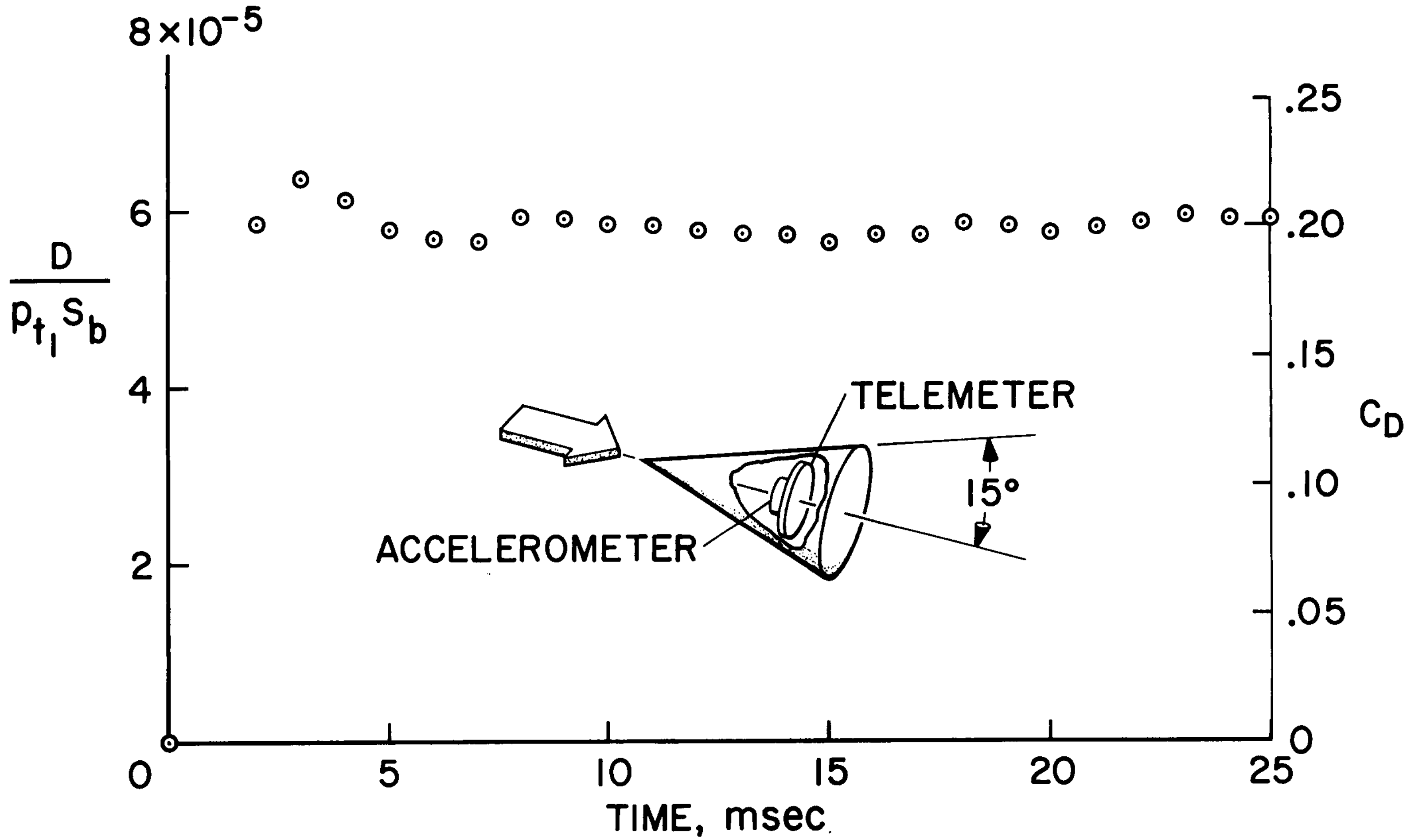

Fig. 4.- Drag measurement by accelerometer for a 15° half-angle cone in 1-foot shock tunnel ($M_\infty \approx 14$, $h_t \approx 10.7\times10^6$ J/kg, $q_\infty/p_{t_1} \approx 2.9\times10^{-4}$).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

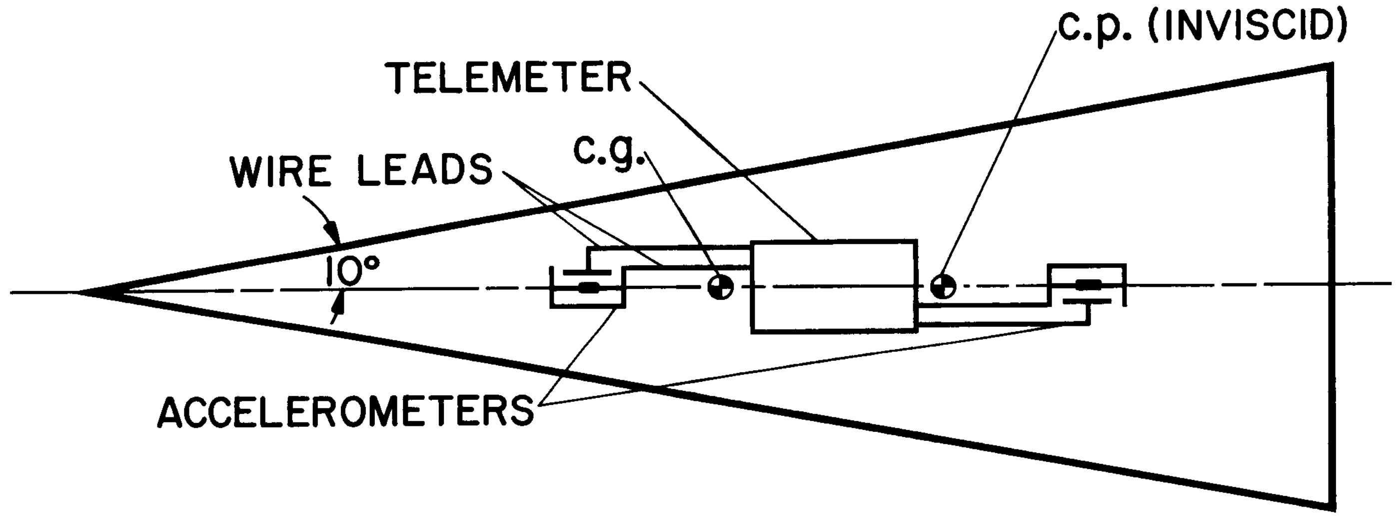

Fig. 5.- Locations of accelerometers for measuring pitch acceleration.

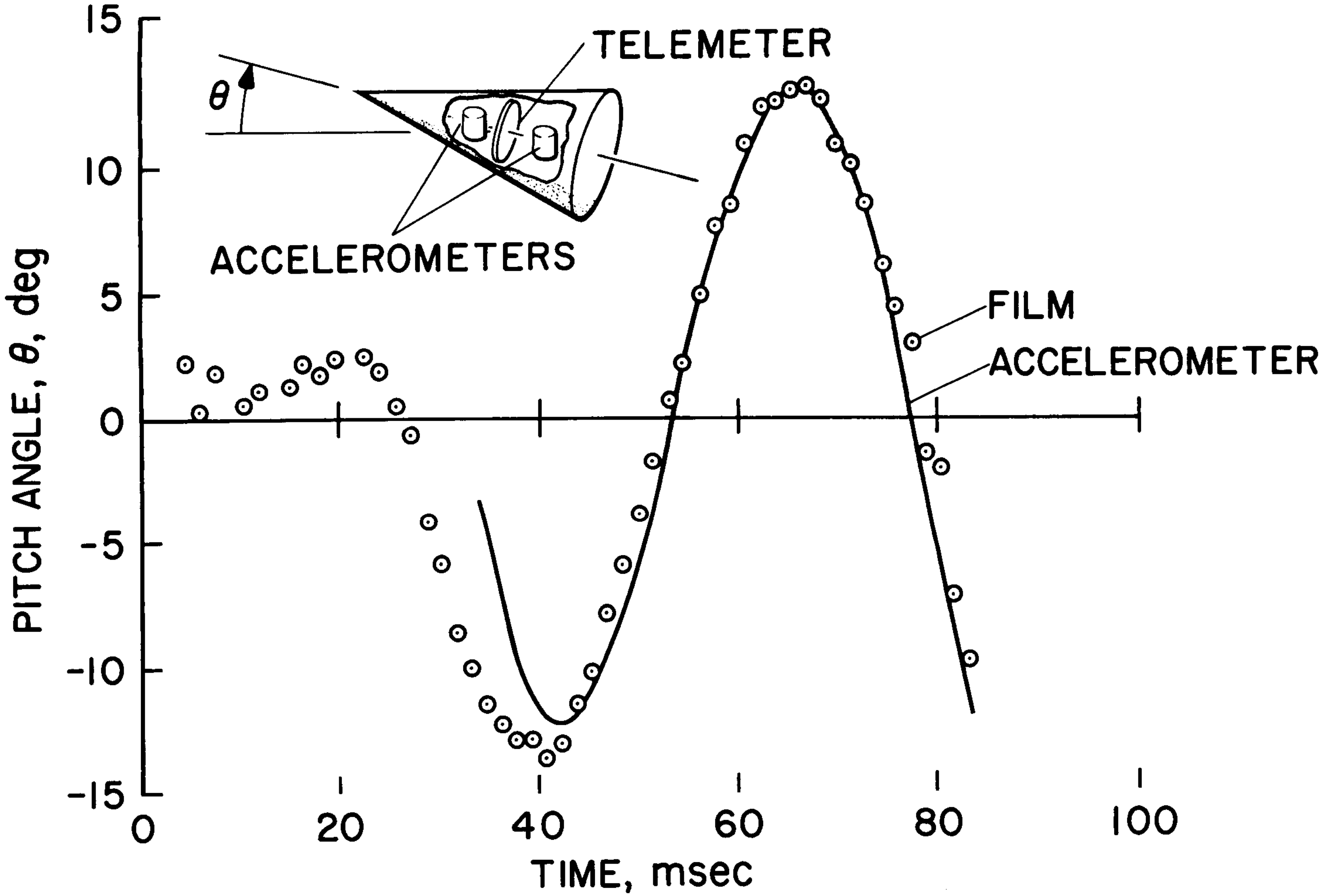

Fig. 6.- Comparison of pitch angles determined from accelerometer and film records for a 15° half-angle cone in 20-inch helium tunnel ($M_\infty \approx 15$, $q_\infty \approx 4.1$ psi).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA